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## Progress studying duststorms using AIRS radiances

Sergio DeSouza-Machado

Atmospheric Spectroscopy Laboratory (ASL)  
University of Maryland Baltimore County Physics Department  
and the

Joint Center for Earth Systems Technology  
ASL Group Members: Larrabee Strow, Scott Hannon and Howard Motteler

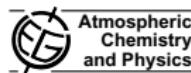
Sept 28, 2006

# The low-down dirt about dust ...

- Dust storms occur all over the world
- Dust storms are now more frequent, because of climatic variability and land change use such as overgrazing or deforestation
- Diseases associated with duststorm outbreaks in Africa?
- Micronutrients transported across oceans (Africa to Amazon)
- Bacteria in dust can kill coral
- Atmospheric forcing due to dust storms can be significant

DeSouza-Machado, Strow, Motteler, Hannon, "Infrared dust spectral signatures from AIRS", GRL v33 (2006)  
Jickells, T., et al. (2005), Global iron connections between desert dust, ocean biogeochemistry and climate, Science, 308, 67

Atmos. Chem. Phys., 6, 613–666, 2006  
www.atmos-chem-phys.net/6/613/2006/  
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## A review of measurement-based assessments of the aerosol direct radiative effect and forcing

H. Yu<sup>1,2</sup>, Y. J. Kaufman<sup>2</sup>, M. Chin<sup>2</sup>, G. Feingold<sup>3</sup>, L. A. Remer<sup>2</sup>, T. L. Anderson<sup>4</sup>, Y. Balkanski<sup>5</sup>, N. Bellouin<sup>6</sup>, O. Boucher<sup>7,8</sup>, S. Christopher<sup>9</sup>, P. DeCola<sup>9</sup>, R. Kahn<sup>10</sup>, D. Koch<sup>11</sup>, N. Loeb<sup>12</sup>, M. S. Reddy<sup>7,13</sup>, M. Schulz<sup>2</sup>, T. Takemura<sup>14</sup>, and M. Zhou<sup>15</sup>

increases with wind speed. Nevertheless, current estimates of aerosol warming effects in the thermal infrared remain highly uncertain, because assessment of the effects requires vertical distributions of aerosol extinction and atmospheric temperature that are not well characterized by either observations or simulations (Sokolik et al., 2001; Lubin et al., 2002). Aerosol optical properties in the thermal infrared range are rarely measured directly, hence the estimates of the thermal infrared effect depend largely on assumed aerosol models. In addition, the scattering effect in the thermal infrared domain is generally neglected in most GCMs, which may lead to an underestimate of the thermal infrared aerosol effect (Dufresne et al., 2002).

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# Dust and AIRS radiances

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- AIRS has sensitivity to dust spectral signatures
- Can use AIRS radiances day and night, over sea and land to
  - detect dust
  - retrieve optical depths
  - obtain quick estimates of OLR forcing
- AIRS data used operationally by several weather centers
- Significant fraction (10%) of AIRS observations dust contaminated
- If not removed from the radiances, dust can negatively impact retrievals ...

# Long Range Transport of Sahara Dust

## AIRS data for July 2003

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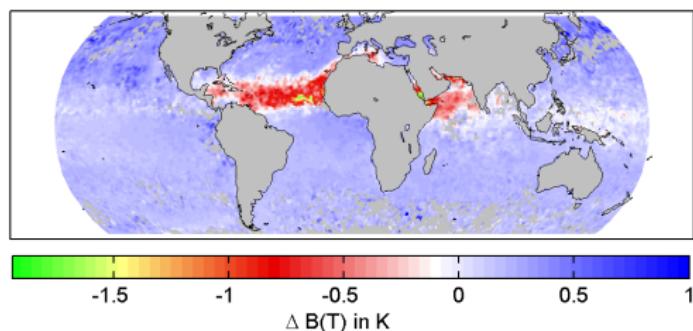
*Dusty sky*

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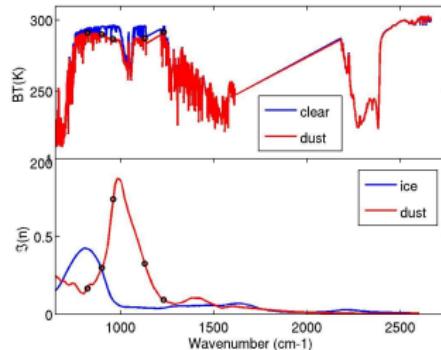
*MAERI data*

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- Use SARTA-CLOUDY code, as well as actual AIRS data, to set up a series of “threshold dust cloud tests” over ocean
- 5 channels chosen are [822.4 900.3 961.1 1129.03 1231.3]  $\text{cm}^{-1}$
- Tests involve split window brightness temperature differences
- Scores accumulated depending on how stringent the tests are
- FOV flagged as “dust contaminated” past certain threshold
- JPL-NASA (Sung-Yung Lee) use  $t=380$  over water
- Tentatively set  $t=360$  over land, with same tests!

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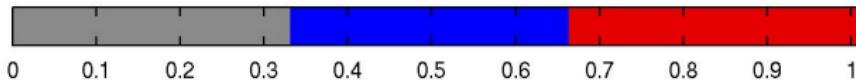
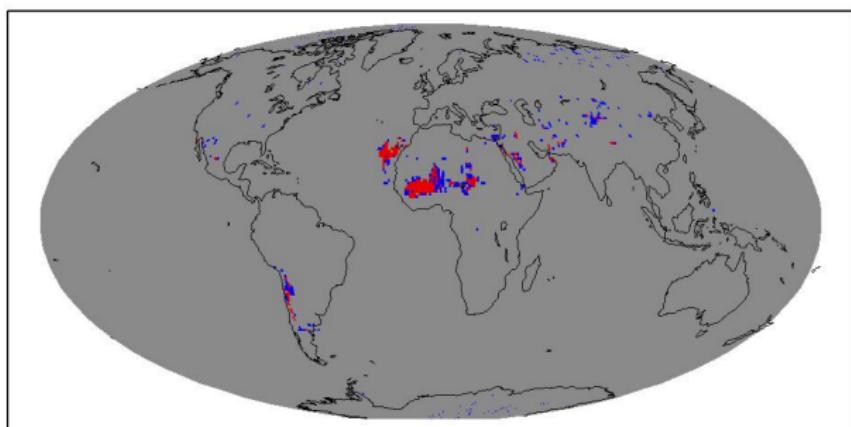
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## DustFlag applied over Sea and Land March 08, 2006

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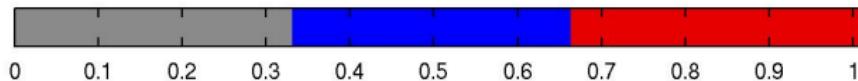
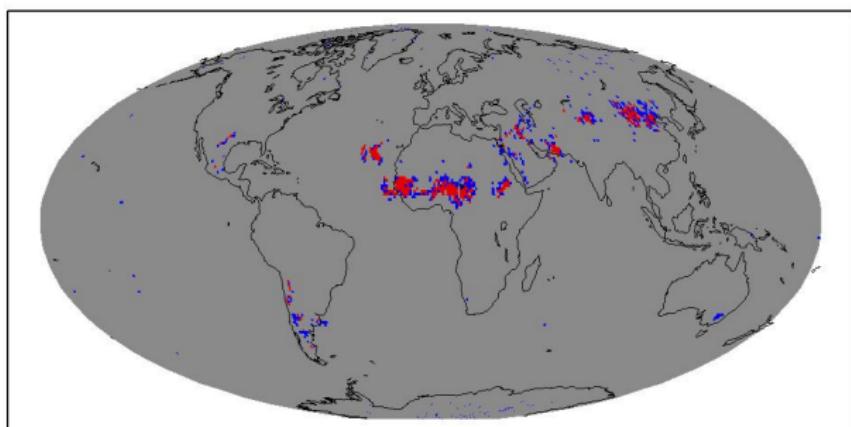
detected dust 03/08/2006



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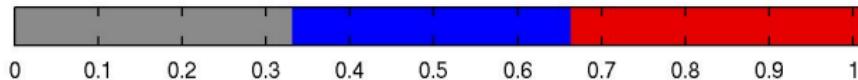
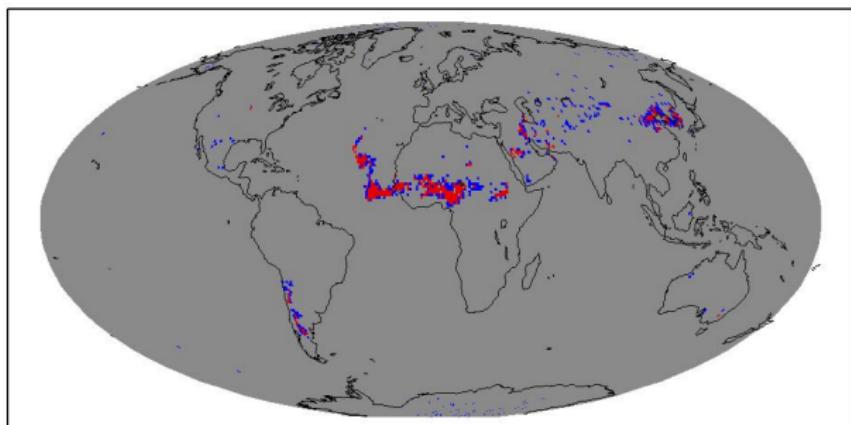
detected dust 03/09/2006



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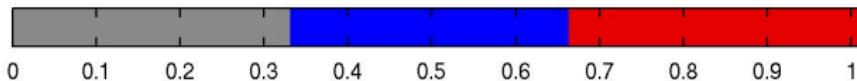
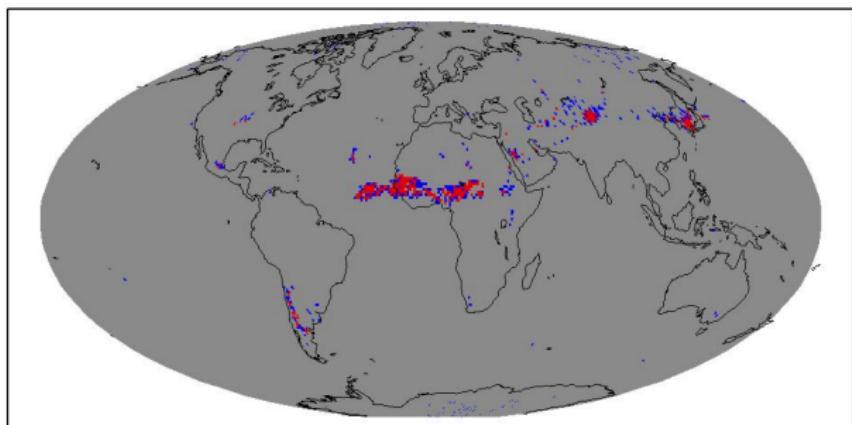
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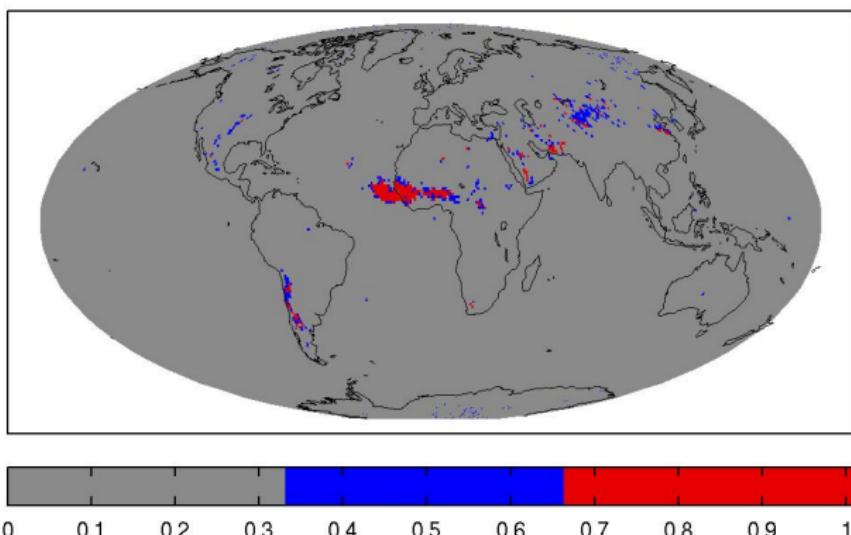
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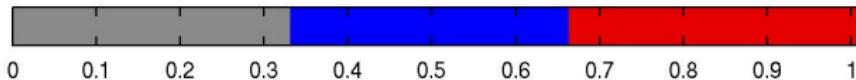
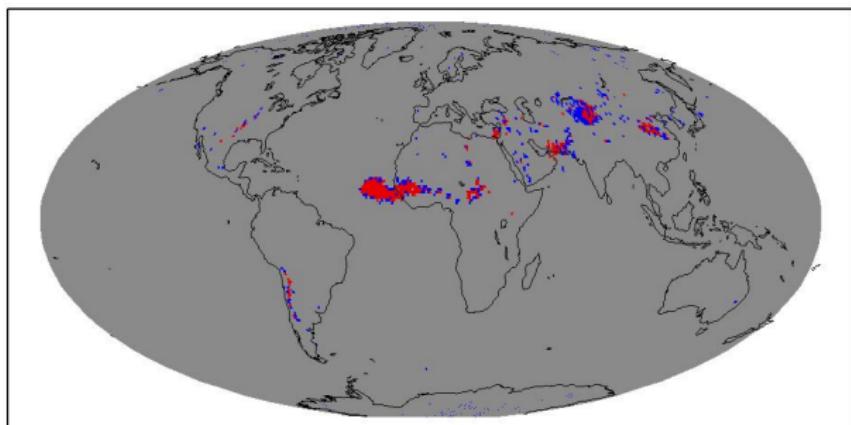
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detected dust 03/12/2006



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detected dust 03/13/2006

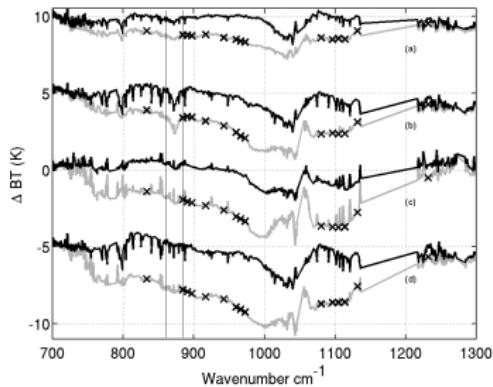


# ASL

## Retrieval of Dust Optical Depths Over Ocean and Land

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- use SARTA (PCLSAM : Chou et al, AMS Jan 1999 pg 159) with adjusted SST (George Aumann) for sea and land
- uses Masuda emissivity for ocean
- uses Global Infrared Land Surface Emissivity Database (SSEC/U.Wisc) (E. Borbas, S. Wetzel-Seemann, R. O. Knuteson, P. Antonelli, J. Li and H.-L. Huang)
- uses ECMWF (or AIRS retrievals) for T(z),Q(z) fields
- retrieve only for FOVs tagged as "dust contaminated"
- weighted average of  $BT_i^{obs} - BT_i^{calc}$ , and  $(BT_i^{obs} - BT_j^{obs}) - (BT_i^{calc} - BT_j^{calc})$  for selected set of thermal IR channels
- use linear fit with SARTA CLOUDY to estimate cloud loading  $n$   
$$BT_i^{obs} = BT_i^{calc}(n) + \delta BT_i^{errors}$$
- very fast  $\leq 1$  second per profile (even if looping over *ptop, dme*)

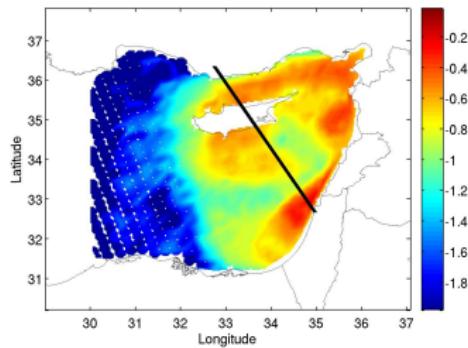
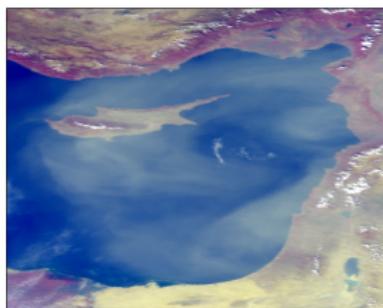


- (a) Libyan/Egyptian coast (02/28/2005)
- (b) Eastern Mediterranean (10/19/2005)
- (c) China Sea (11/12/2002)
- (d) W. African coast (07/25/2004)
  - All show the "V" shape in  $800\text{-}1200\text{ cm}^{-1}$  (silicate absorber)
  - Notch feature between 860 and  $880\text{ cm}^{-1}$  is strongest in *b, c*

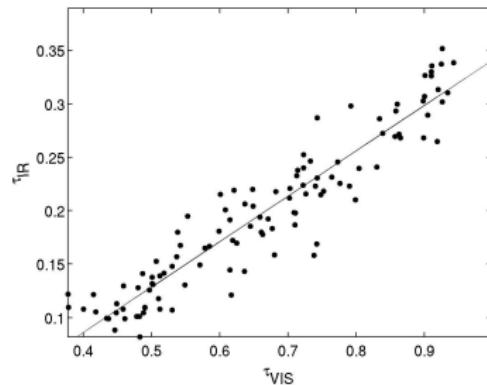
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# AIRS Retrieval October 19, 2002 over E. Mediterranean

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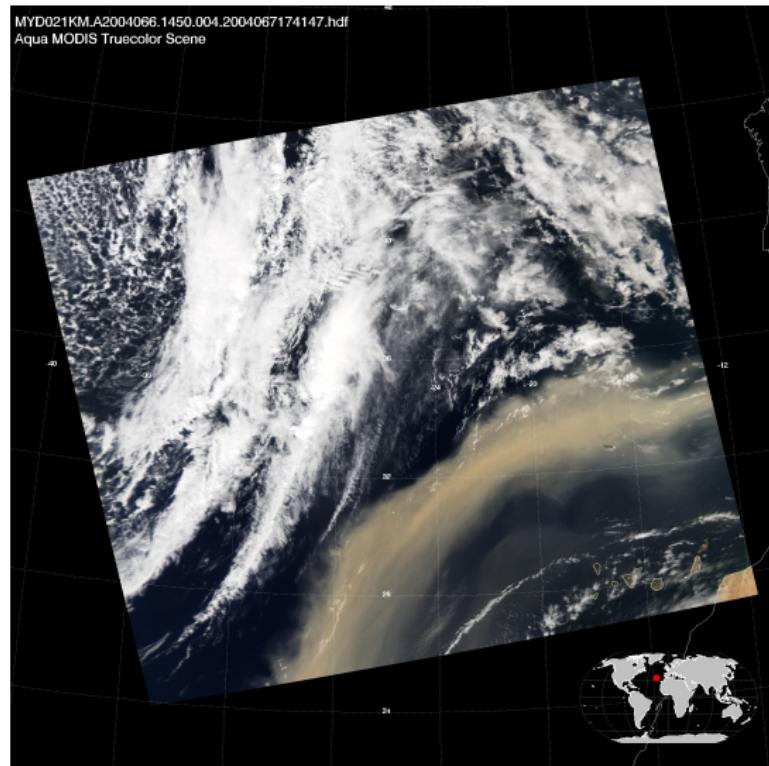


# Comparing MODIS to AIRS



MODIS channel 2 (0.55  $\mu\text{m}$ ) compared to AIRS 900  $\text{cm}^{-1}$   
 $\tau_{IR} = 0.425\tau_{VIS} - 0.084$ , with a correlation of 0.935

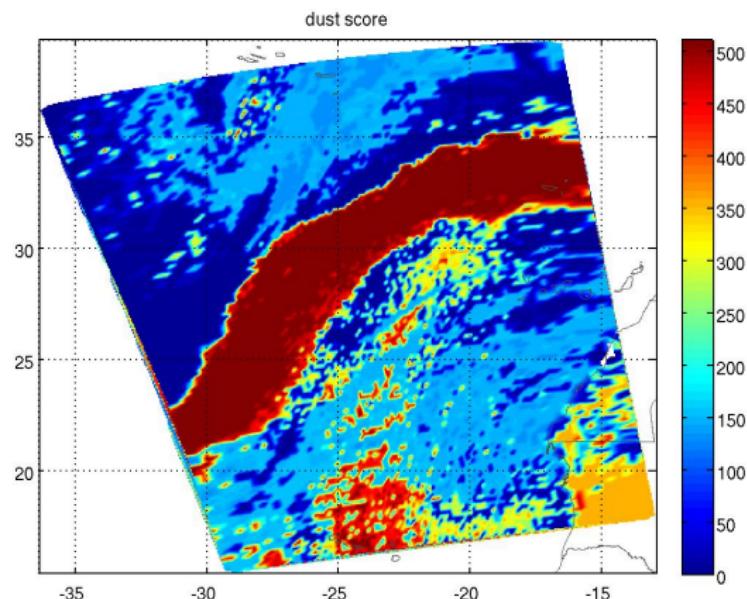
# True color image made from MODIS data, for March 6, 2004 at approximately 1430 UTC



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# Dustflag applied to AIRS radiance spectra, for same duststorm

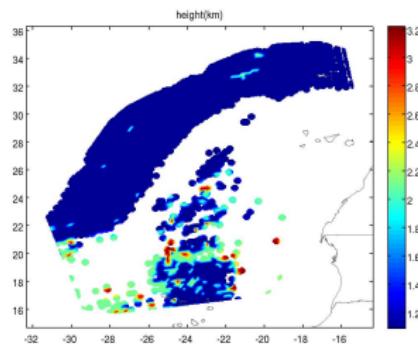
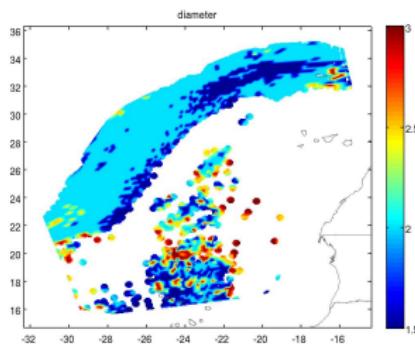
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Pixels with a score above 380 are flagged as dust contaminated.

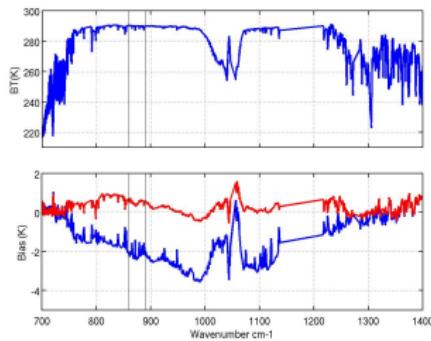
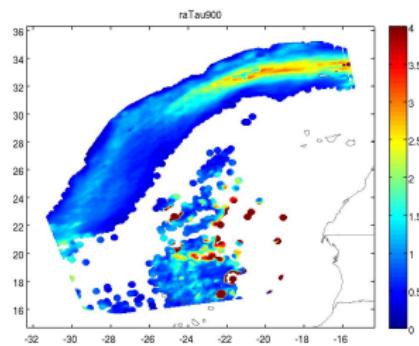
# Diameter and Height retrieval

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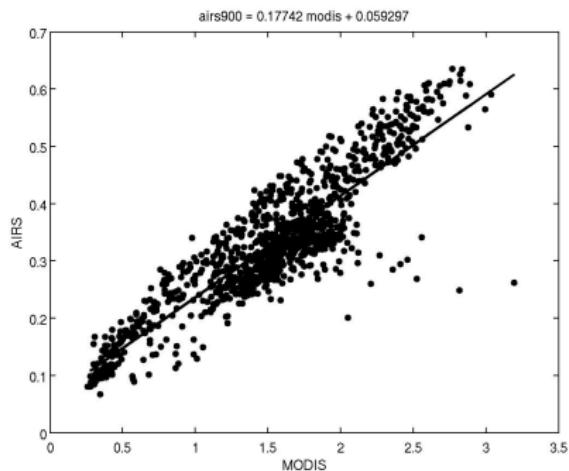


# Optical Depth and Bias

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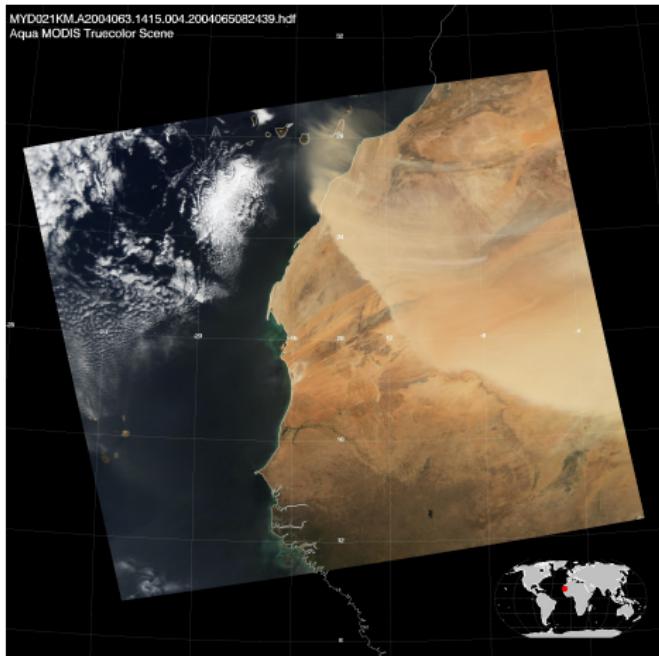


## AIRS vs MODIS regression at 600 mb



AIRS infrared optical depths at  $900\text{ cm}^{-1}$  plotted against MODIS Ch 2 (550 nm) visible optical depths, for dusttop at 600 mb. At 900 mb (1.0 km),  $\frac{\tau_{\text{AIRS}}}{\tau_{\text{MODIS}}} \simeq 0.5$

## MODIS image of duststorm on March 3, 2004 over N.W.Africa



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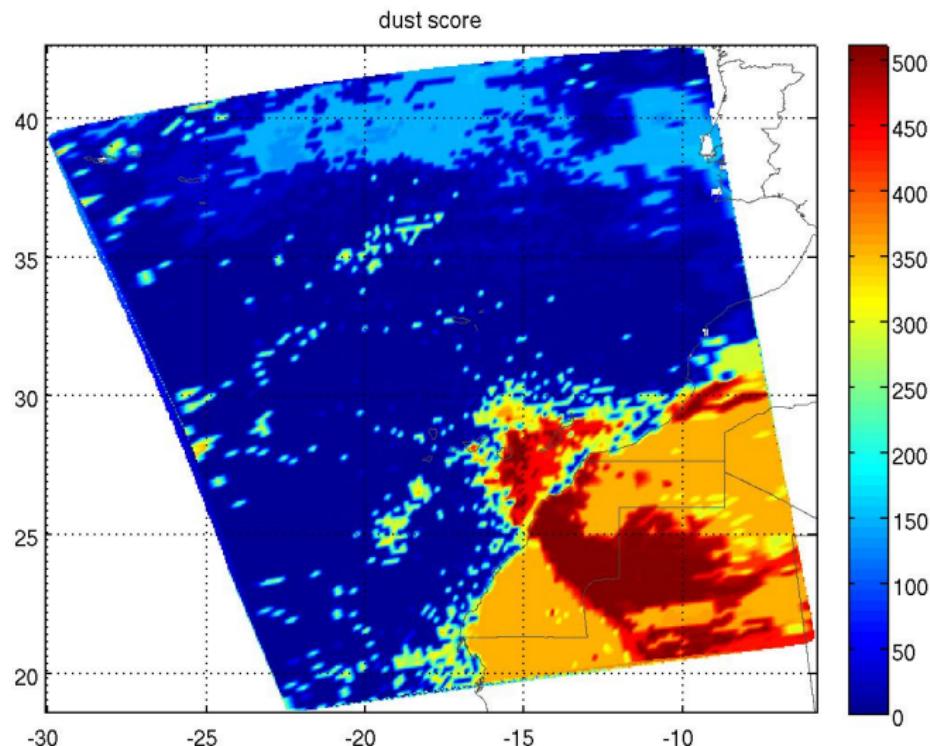
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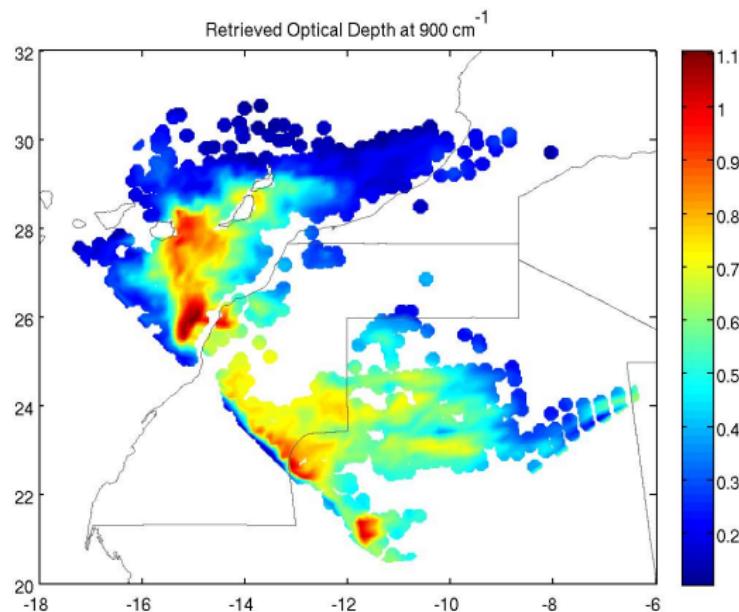
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# Dust flag using AIRS IR data

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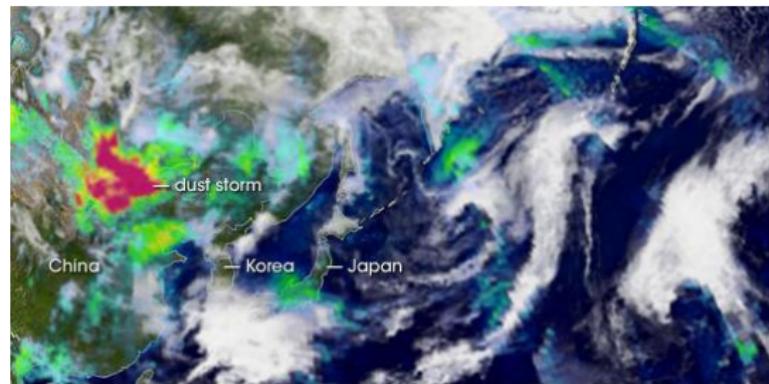


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Emissivity from using Bob Knuteson's on/off line technique, for clear FOVs from other days at same general location

<http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php>



Aerosol Index

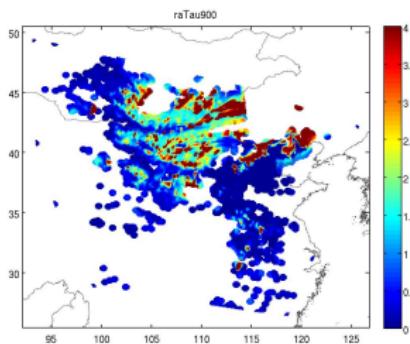
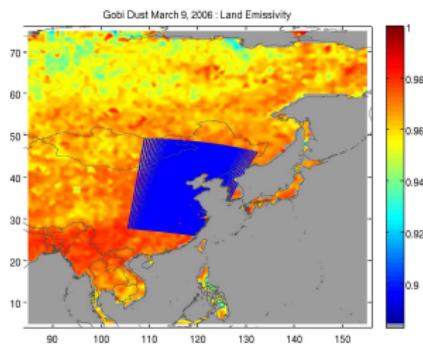


Aerosol index  $AI > 0$  absorbing aerosols,  $< 0$  pure scattering aerosols

$$AI = 100 \log_{10} \frac{I_{\text{measured}}(360\text{nm})}{I_{\text{Rayleigh calculated}}(360\text{nm})}$$

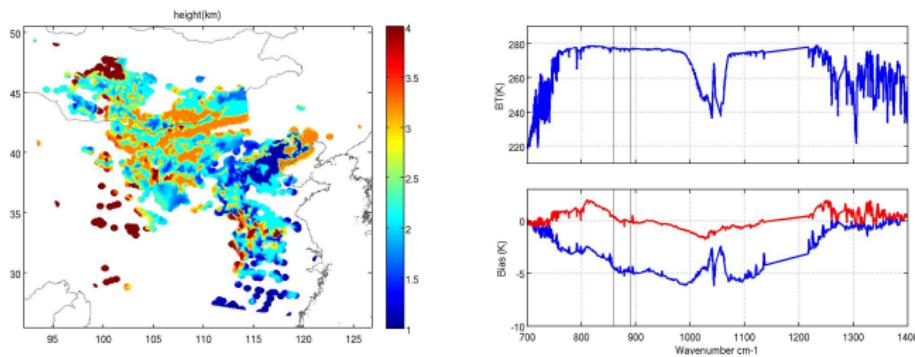
## 9 March 2006, AIRS retrievals

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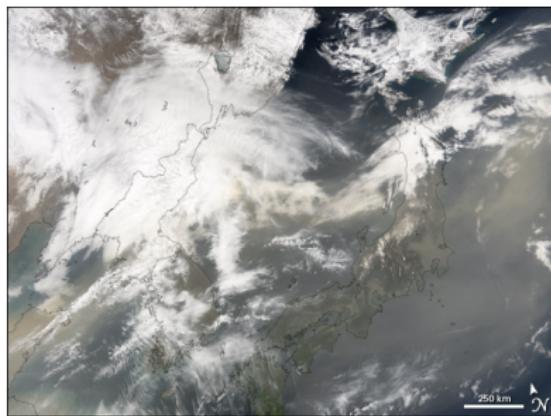
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Images are for day and night AIRS granules (061,181)  
 $\langle \text{dme} \rangle \simeq 1.5 \text{ } \mu\text{m}$

# Gobi Desert Dust Storm April 2006

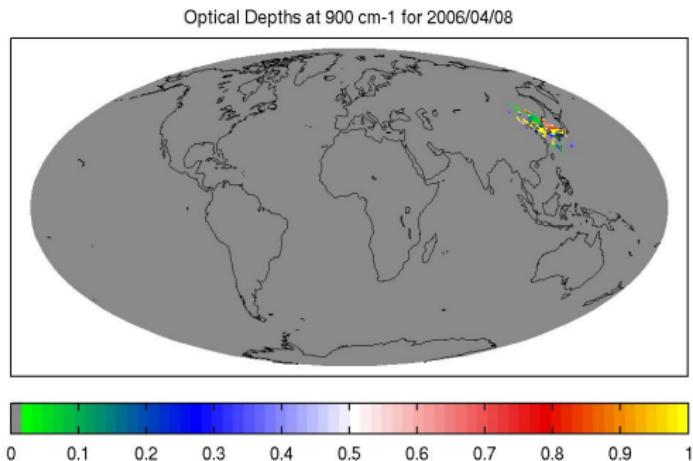
[http://earthobservatory.nasa.gov/NaturalHazards/natural\\_hazards\\_v2.php3?img\\_id13505](http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id13505)



April 8, large dust storm originated in inner Mongolia, and started travelling east, across the Pacific Ocean and reaches west coast of USA 6 days later.

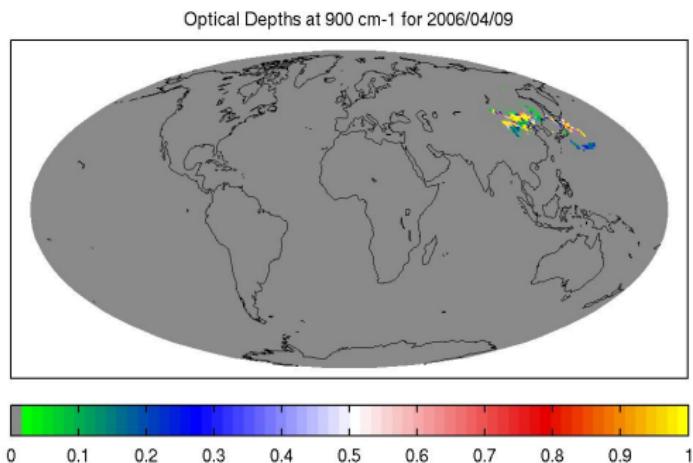
Sergio DeSouza-Machado (UMBC), Sung-Yung Lee, Eric Fetzer, Brian Kahn, Bjorn Lambrigtsen, Sharon Ray (Jet Propulsion Laboratory)

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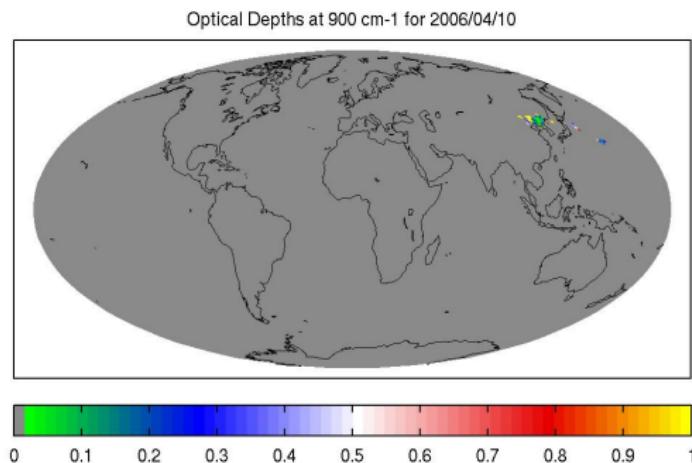


Optical depth at 900 cm<sup>-1</sup>

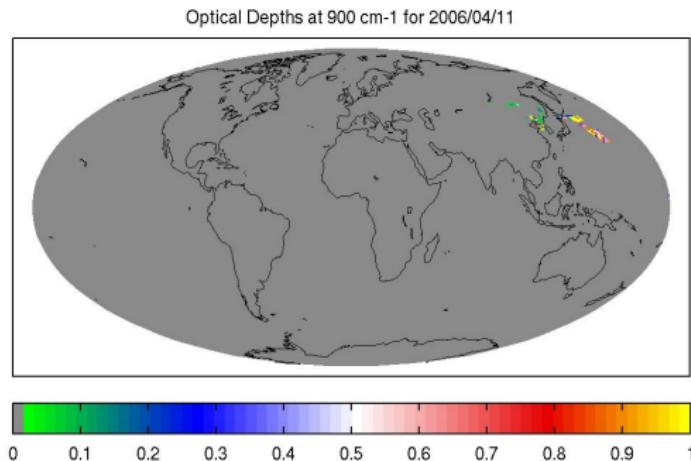
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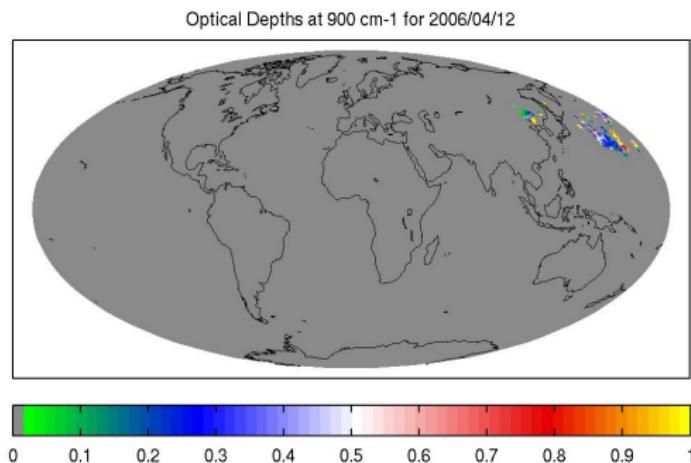
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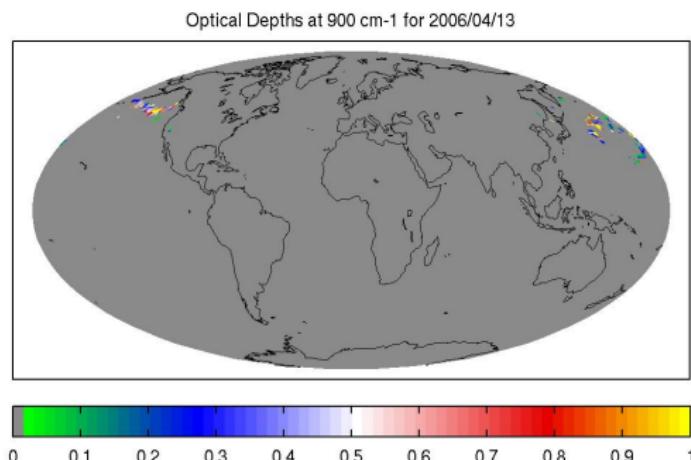
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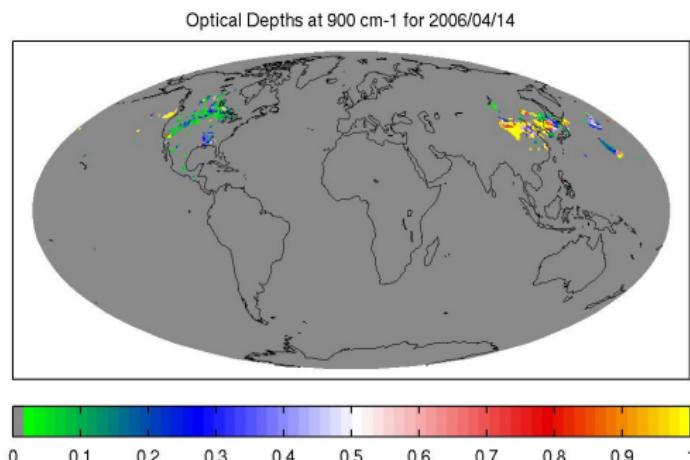
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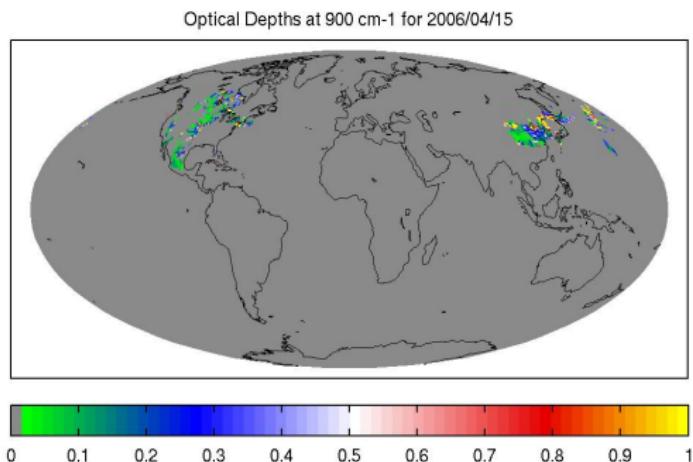
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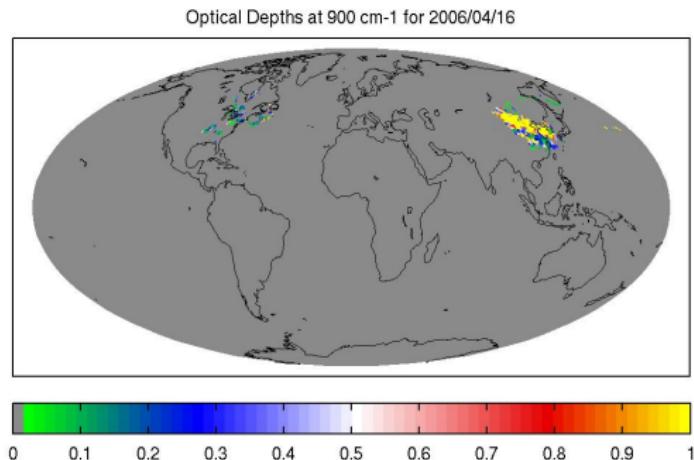
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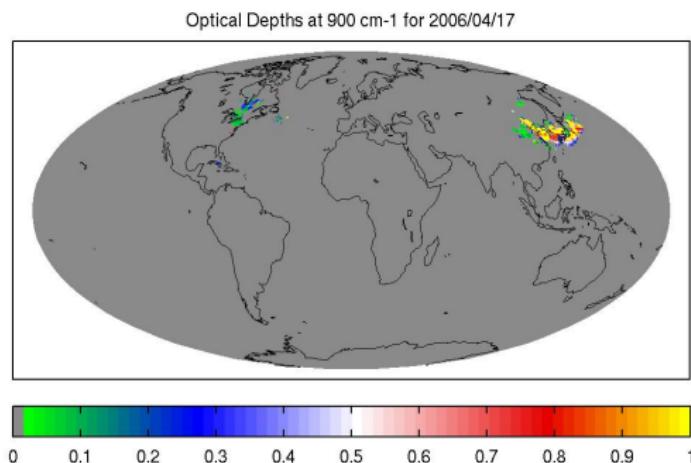
## 15 April 2006, AIRS retrievals

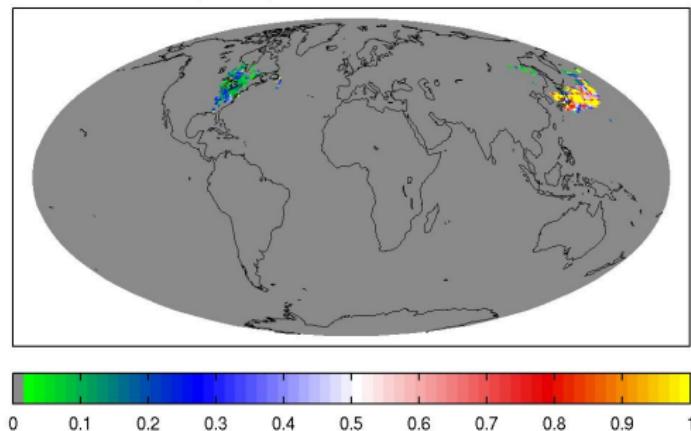
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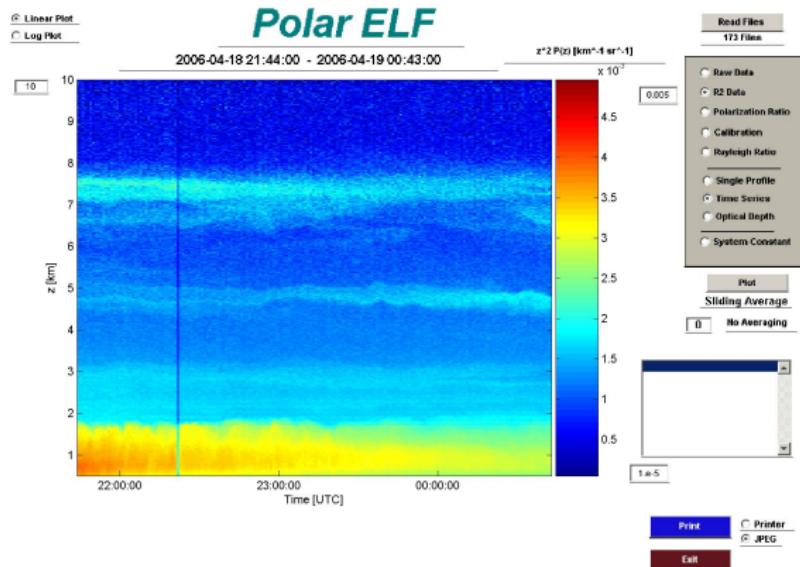


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Courtesy of Ray Rogers and Ray Hoff (UMBC)

### Radiance at the top of a clear sky atmosphere

$$R(\nu, \theta) = \epsilon_s B(\nu, T_s) \tau_{1 \rightarrow N}(\nu, \theta) + \sum_{i=1}^{i=N} B(\nu, T_i) (\tau_{i+1 \rightarrow N}(\nu, \theta) - \tau_{i \rightarrow N}(\nu, \theta))$$

### Outgoing Longwave Radiation from top of a clear sky atmosphere

Let  $\cos(\theta) = \mu$

$$OLR = 2\pi \int_0^\infty d\nu \int_0^1 R(\nu, \mu) \mu d\mu$$

$B(\nu, T_i)$  indpt of angle; evaluate terms of the form

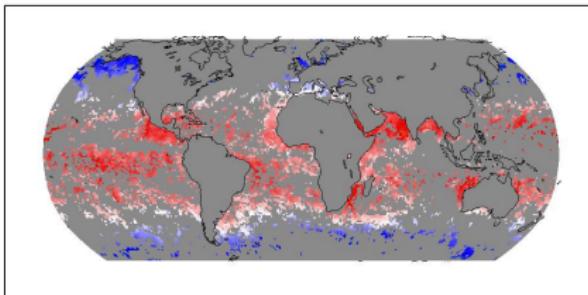
$$\int_0^1 \mu d\mu e^{-k_{i+1 \rightarrow N}/\mu}$$

These are Exponential Integrals of the Third Kind  $E_3(k_{i+1 \rightarrow N})$

# kCARTA/SARTA (AIRS) OLR model

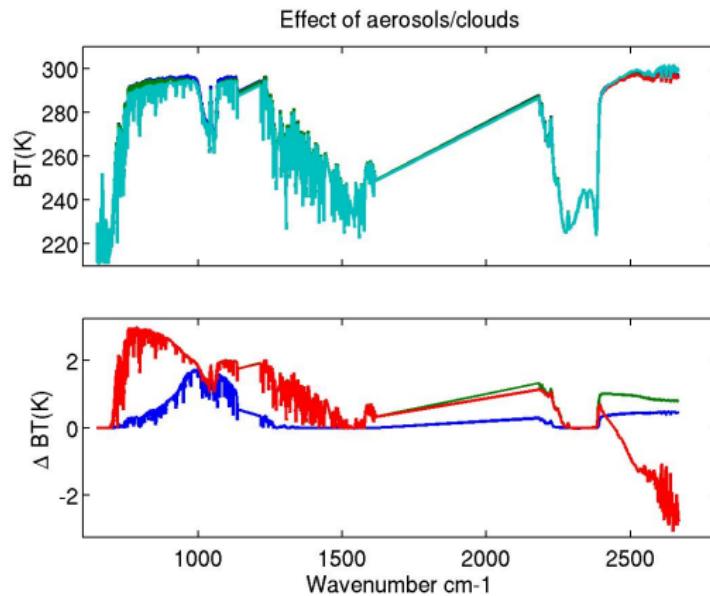
- Current kCARTA database limited to 605 - 2830 cm<sup>-1</sup>
- Should extend this to the Far-IR on ( $\geq 50 \text{ cm}^{-1}$ )
- Typical OLR at tropics  $\simeq 340 \text{ W/m}^2$ ; kCARTA  $\simeq 180 \text{ W/m}^2$  which is  $\simeq$  ratio of areas under Planck curve (kCARTA : entire)
- Train the results of 48 regression profiles against SARTA radiances/BTs to make set of regression coefficients
- Model needs ECMWF/AIRS L2 profiles, nadir rads for  $\simeq 50$  channels
- Results of prelim model : uniform clear FOVs Jan 1-7, 2005

Jan 1-7, 2005 OLR as measured by AIRS



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Aerosols and clouds affect outgoing radiation  
eg look at Tropical Profile with dust and cirrus



# Climate Forcing by clouds/aerosols/dust

Literature eg J.Zhang/S. Christopher and H. Yu, Y. Kaufman *et.al.*  
Atmospheric Chem and Physics : John Seinfeld, Spyros Pandis

- Negative feedback : more atmospheric water vapor → increased clouds → reflect sunlight → cooler planet
- Positive feedback : higher convective clouds radiate at lower temps → trap energy (greenhouse) → warmer planet
- **Direct effect** : Small aerosols ( $\leq 1 \text{ um diameter}$ ) scatter solar radiation back to space → cooling the planet eg sulphates from industry
- **Indirect effect** Small aerosols ( $\leq 1 \text{ um diameter}$ ) act as CCN → more aerosol leads to smaller raindrops → reflect sunlight back to space → cooling the planet
- **Magnitude of climate forcing by clouds/aerosols is uncertain, especially in the longwave**
- Can use MODIS to identify dusty scenes, MISR to obtain optical depths and CERES to obtain broadband TOA LW flux, or **have potential to use AIRS to study all three over ocean or land**

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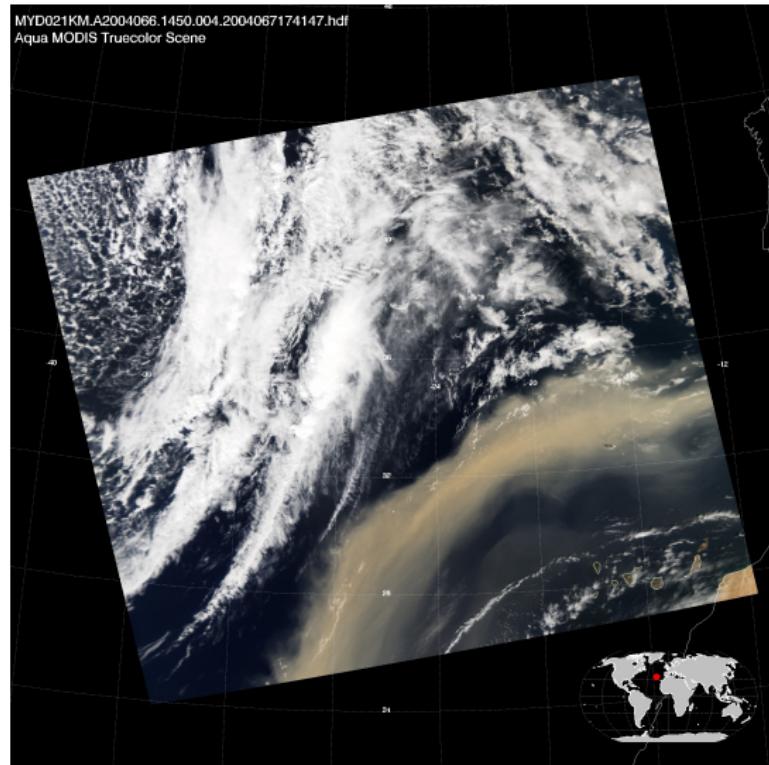
Using the PCLSAM model (Chou et al, AMS Jan 1999 pg 159) can reparameterize optical depth  $\tau$  with atm gases only to  
 $\tau \rightarrow \tau(atm) + \tau(scatter, E, \omega, g)$

Radiance at the top of a cloudy sky atmosphere

$$R(\nu) = \epsilon_s B(\nu, T_s) \tau_{1 \rightarrow N}(\nu, \theta) + \sum_{i=1}^{i=N} B(\nu, T_i) (\tau_{i+1 \rightarrow N}(\nu, \theta) - \tau_{i \rightarrow N}(\nu, \theta))$$

This is same as before, and so can compute OLR by using E3!!

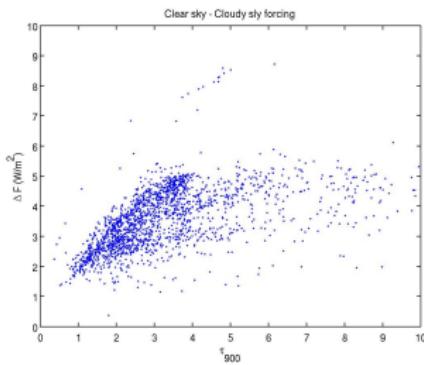
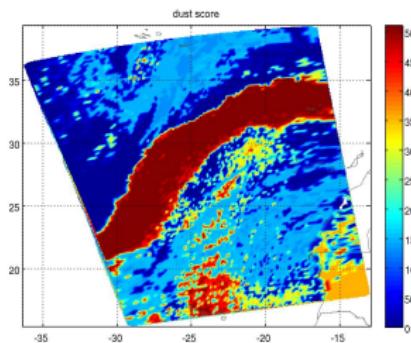
# True color image made from MODIS data, for March 6, 2004 at approximately 1430 UTC



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# Dustflag and OLR forcing applied to AIRS radiance spectra

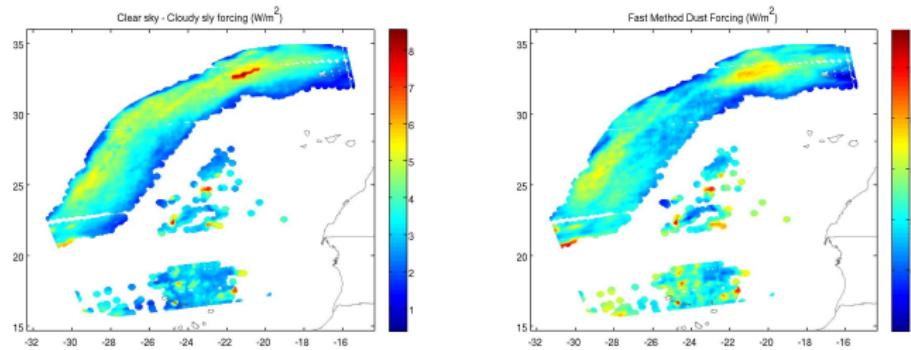
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Left : Dustflag (threshold - 380 over ocean)

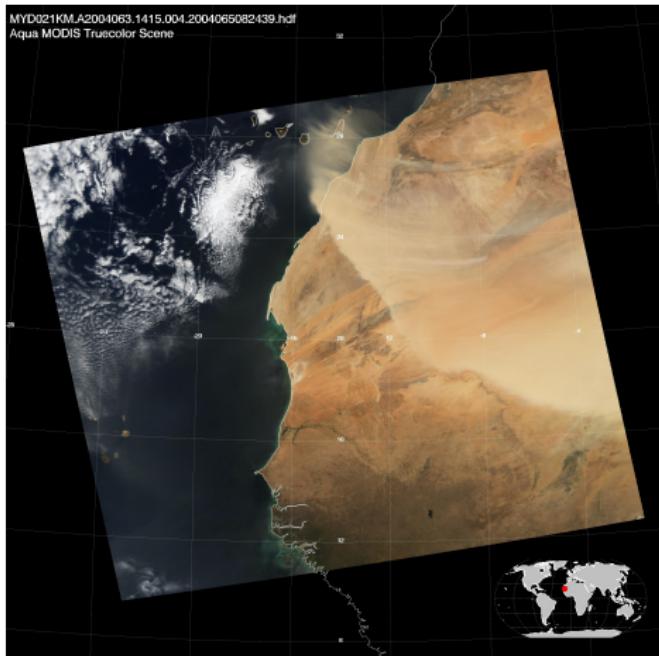
Right : OLR forcing (clear - cloudy) versus retrieved  $\tau(900\text{cm}^{-1})$

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Left : using PCLSAM and kCARTA, about 6 minutes per profile  
Right : using  $\sum_{i=1}^{2378} (rcl_{ri} - robs_i) \pi$ , **Extremely FAST!!!!**  
 $\Delta \simeq$  same as PCLSAM

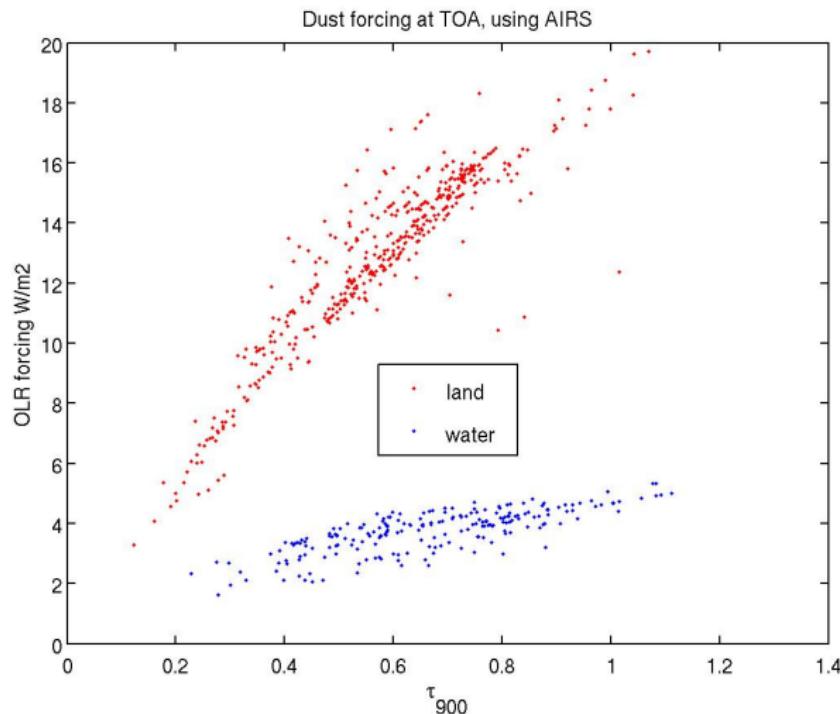
## MODIS image of duststorm on March 3, 2004 over N.W.Africa



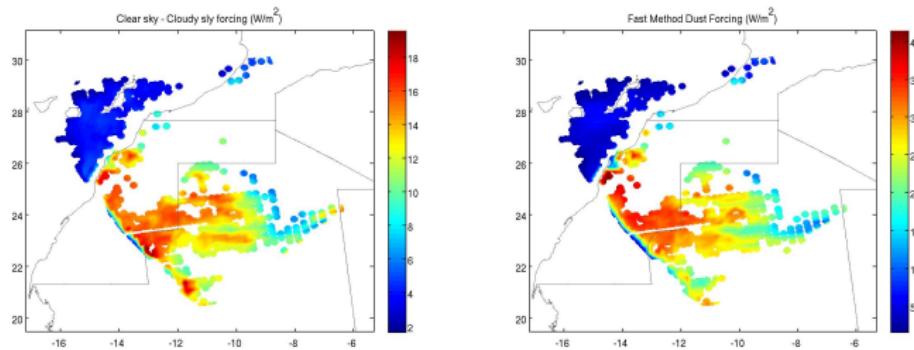
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# Dust forcing over land and water

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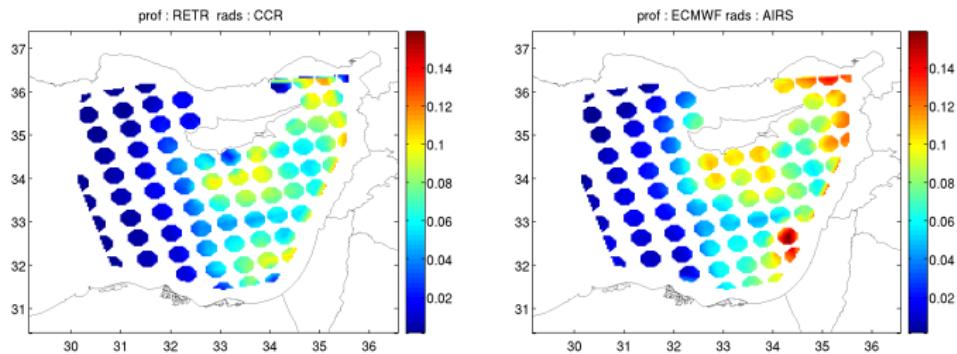
Left : using PCLSAM and kCARTA, about 6 minutes per profile  
Right : using  $\sum_{i=1}^{2378} (rcl_{ri} - robs_i) \pi$ , **Extremely FAST!!!!**  
 $\Delta \simeq 2 \times$  PCLSAM over land

- Strong duststorms can have uniform enough dust that it can make it through “uniform clear” stage
- This could negatively impact AIRS retrievals
  - Effects could end up in the emissivity, without affecting  $T(z), Q(z)$
  - Some preliminary investigations show that  $Q(z)$ (AIRS) are “drier” than corresponding ECMWF fields, especially where the dust is
- Plan to investigate “taking out effects of dust”  
$$R_i^{obs} = R_i^{clear} + \delta R_i^{dust}$$

# Retrieved optical depths : October 19, 2002 (granule 107)

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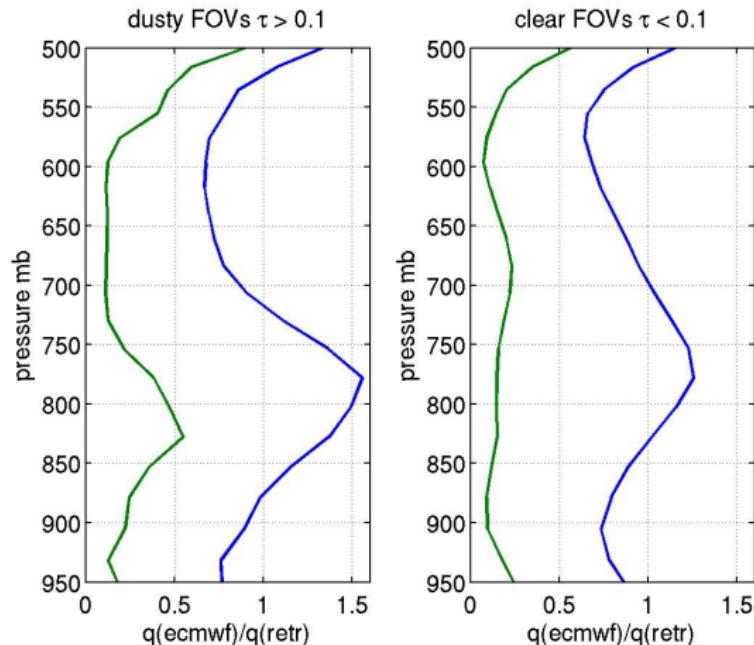
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- Retrieved optical depths using about 15 thermal IR channels
- Left : using profiles from AIRS retrievals and cloud cleared radiances
- Right : using profiles from ECMWF and AIRS observations

Water vapor  $q(z)$  ratios Oct 19 2002

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- Blue = Mean; Green = Std
- 55 cloudy profiles (left) 11 clear profiles (right)

- Dr. N. Nalli has provided colocated MAERI data, along with radiosonde profiles, obtained off W. Africa during AEROSE (March 2004); sun photometer data available but no lidar data
- Dr. N. Nalli will be providing data from AEROSE II campaign (June 2006) where he will also have sun photometer, ozone radiosondes, lidar data

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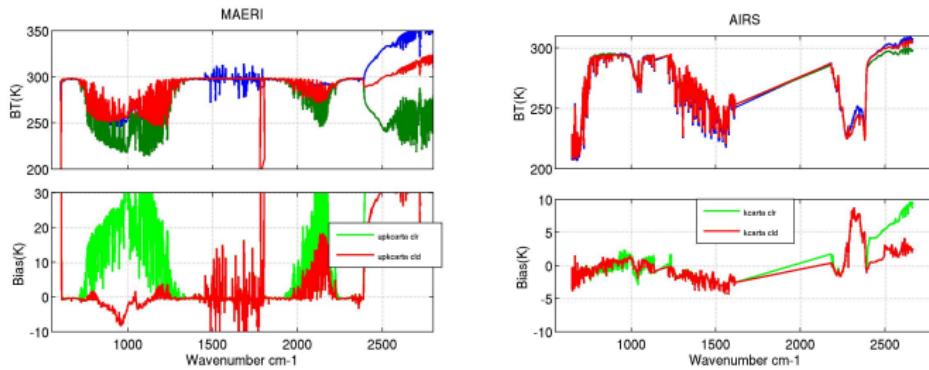
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AEROSE I March 07, 2004 DAY (top = spectra,  
bottom = bias)

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- Cannot simultaneously fit AIRS and MAERI data
- Also might have sunglint problems??
- AIRS sim : dust 1000 - 900 mb,  $D \simeq 1.5 \text{ um}$ ,  
 $\tau(900\text{cm}^{-1}) \simeq 1.02$
- MAERI sim : dust 1000 - 900 mb,  $D \simeq 2.5 \text{ um}$ ,  
 $\tau(900\text{cm}^{-1}) \simeq 0.4$

# Conclusion

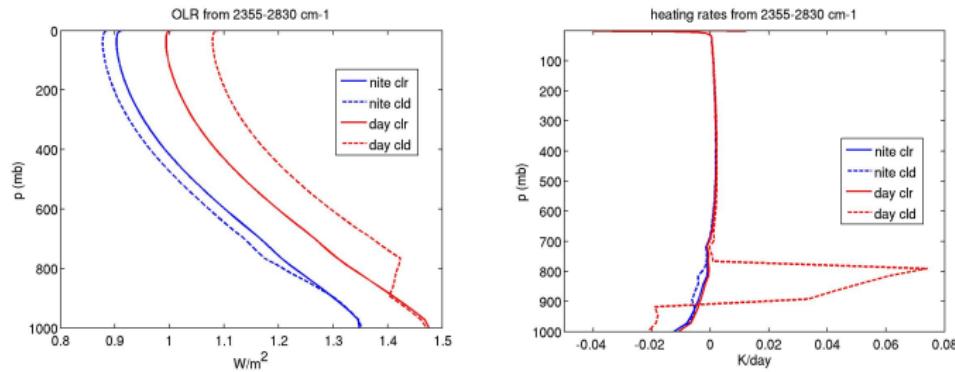
- Dust Flag works over ocean and land
- Rapid dust retrievals over ocean and land
- Rapid estimates of OLR forcing by dust
- Will start looking into removing the effects of dust from AIRS radiances
- Will start using MAERI data from AEROSE campaigns to improve retrieval codes (Nick Nalli/NOAA)



<http://earthobservatory.nasa.gov/>  
<http://www-air.sci.jpl.nasa.gov/>  
<http://asl.umbc.edu/>  
sergio@umbc.edu

# SW OLR and Heating rates

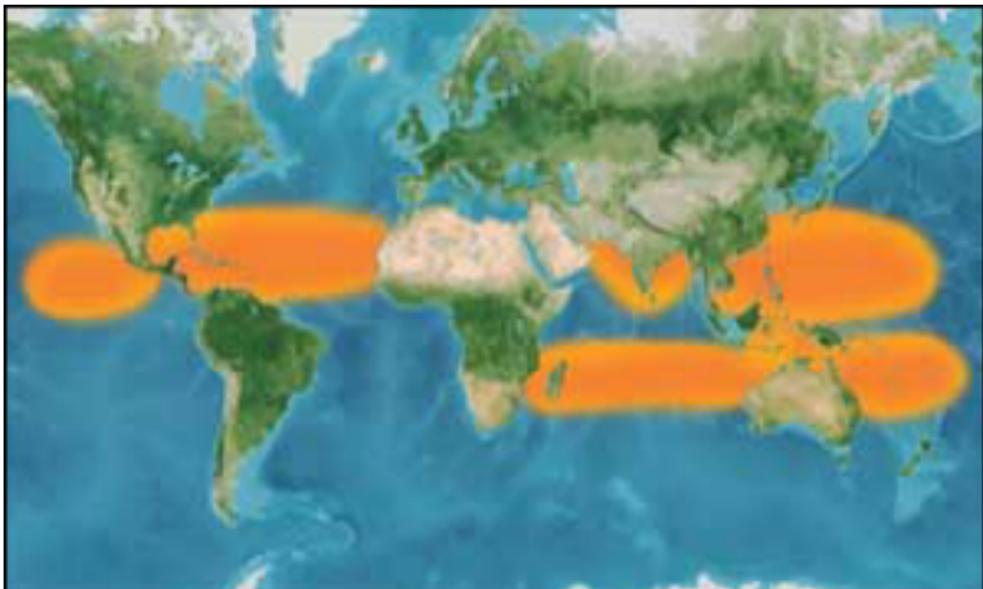
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- Left graph shows OLR (upgoing radiative flux)
- Right graph shows heating rates (Kelvin/day)
- As expected, dust suppresses OLR in the night time, but enhances OLR in the day time (solar reflection from dusttop)

# BBC web site on hurricanes

[http://www.bbc.co.uk/weather/features/understanding/hurricane\\_cycle.shtml](http://www.bbc.co.uk/weather/features/understanding/hurricane_cycle.shtml)



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